

marked up original specification and applicants submit that the Substitute Specification, as submitted on November 29, 2001, should now be entered.

Applicants note that the amendments as effected by the present amendment of the specification are amendments of the Substitute Specification.

As to the rejection of claims 2, 3, 7 and 8 under 35 U.S.C. §112, second paragraph, as being indefinite, this rejection is traversed insofar as it is applicable to the present claims, and reconsideration and withdrawal of the rejection are respectfully requested.

Applicants note that claims 2, 7 and 8 have been amended to delete the recitation of "a means to process plasma using the generated plasma" while claim 3 has been amended to recite a means to control plasma distribution according to the processing procedures stored in said store means so that antecedent basis is now provided. It is noted that each of independent claims 2, 7 and 8 have been amended to recite a plasma processing apparatus to provide plasma processing of a substrate by plasma, while clarifying other features. With respect to claim 7 and the limitation questioned by the Examiner, applicants note that claim 7 has been amended to recite the feature that the plasma processing apparatus further includes a RF bias circuit which is floated with respect to ground so as to send RF current to the substrate to be processed. The Substitute Specification at pages 27 and 28 have been amended to clarify the feature that radio frequency power is applied to the stage electrode 3 from the bias power supply 17 through the transformer 29 and that radio frequency current passes through the substrate 15 and the plasma and flows to facing electrodes 2a and 2b. As indicated at pages 27 and 28, the transformer 29 and the bias power supply 17 is separated from or is floated with respect to ground so that almost all of the radio frequency current flowing from the stage electrode 3 is fed to facing electrodes 2a and 2b without going to other places and current returns to the transformer from the facing electrodes 2a and 2b through low pass filters 13a

and 13b. Thus, applicants submit that the language as now utilized in claim 7 finds clear support in the specification in the portion indicated. Likewise, claim 8 has been amended to recite the feature of multiple RF current conducting means installed at a position opposite to a position where the substrate to be processed is mounted, and that the multiple RF current conducting means are provided with means to control a ratio of RF current flowing from the substrate to be processed to each of the RF current conducting means. As described in the specification of this application, at pages 27-29 of the specification, RF current flows from the stage electrode 3 to facing electrodes 2a and 2b and returns via the low pass filters 13a and 13b which are controllable by the drive motor and distribution control as described at page 29 and the paragraph bridging pages 29 and 30, for example. Thus, applicants submit that the claimed features as recited in the claims of this application are in compliance with 35 U.S.C. §112, second paragraph, and are supported in the description in the specification.

Applicants note that in accordance with the present invention, an energy state of electrons can be controlled independently in the plasma processing apparatus so that it becomes possible to attain both a high selective etching and a high precision high-speed etching simultaneously, which features have not been provided in the prior art arrangements.

As to the rejection of claims 1, 2, 7 and 8 under 35 U.S.C. 103(a) as being unpatentable over Otsubo et al (Japanese Patent Publication 11-260596) in view of Yamagata et al (US 5,362,358) and the rejection of claim 3 under 35 U.S.C. 103(a) as being unpatentable over Otsubo et al in view of Yamagata et al and further in view of Misono et al (Japanese Patent Publication 08-167588), such rejections are traversed insofar as they are applicable to the present claims, and reconsideration and withdrawal of the rejections are respectfully requested.

With regard to the requirements to support a rejection under 35 U.S.C. 103, reference is made to the decision of In re Fine, 5 USPQ 2d 1596 (Fed. Cir. 1988), wherein the court pointed out that the PTO has the burden under §103 to establish a prima facie case of obviousness and can satisfy this burden only by showing some objective teaching in the prior art or that knowledge generally available to one of ordinary skill in the art would lead that individual to combine the relevant teachings of the references. As noted by the court, whether a particular combination might be "obvious to try" is not a legitimate test of patentability and obviousness cannot be established by combining the teachings of the prior art to produce the claimed invention, absent some teaching or suggestion supporting the combination. As further noted by the court, one cannot use hindsight reconstruction to pick and choose among isolated disclosures in the prior art to deprecate the claimed invention.

Furthermore, such requirements have been clarified in the recent decision of In re Lee, 61 USPQ 2d 1430 (Fed. Cir. 2002) wherein the court in reversing an obviousness rejection indicated that deficiencies of the cited references cannot be remedied with conclusions about what is "basic knowledge" or "common knowledge".

The court pointed out:

The Examiner's conclusory statements that "the demonstration mode is just a programmable feature which can be used in many different device[s] for providing automatic introduction by adding the proper programming software" and that "another motivation would be that the automatic demonstration mode is user friendly and it functions as a tutorial" do not adequately address the issue of motivation to combine. This factual question of motivation is immaterial to patentability, and could not be resolved on subjected belief and unknown authority. It is improper, in determining whether a person of ordinary skill would have been led to this combination of references, simply to "[use] that which the inventor taught against its teacher."... Thus, the Board must not only assure that the requisite findings are made, based on evidence of record, but must also explain the

reasoning by which the findings are deemed to support the agency's conclusion. (emphasis added)

Turning to Otsubo et al, as recognized by the Examiner, this reference "fails to specifically teach an electromagnetic wave power control means" (emphasis added). More particularly, the language of claim 1 is "a radiated electromagnetic wave power control means to control the radiated electromagnetic wave power through radio frequency displacement control means forming a resonant circuit" (emphasis added). Applicants note that the radiated electromagnetic wave power control means of the present invention is described in the paragraph bridging pages 21 and 22 of the Substitute Specification, for example, and describes that electromagnetic waves are radiated in direct proportion to the radio frequency displacement current flowing to insulating 4b which electromagnetic waves are radiated into the process chamber 1 through the space between covers 8b and 8c, and the electromagnetic wave emission power is controlled by controlling the radio frequency displacement current flowing to the resonant circuit using the capacity of the variable capacitor 11 which is adjusted in the manner described. Again, it is apparent that as recognized by the Examiner, Otsubo et al does not disclose such features and applicants submit that claim 1 and other claims reciting such features patentably distinguish over Otsubo et al in the sense of 35 U.S.C. 103 and should be considered allowable thereover.

The Examiner recognizing the deficiency of Otsubo et al cites Yamagata et al contending that Yamagata et al teaches an electromagnetic wave power control means and it would have been obvious to utilize the same in Otsubo et al. Applicants submit that contrary to the position set forth by the Examiner, Yamagata et al does not disclose an electromagnetic wave power control means as disclosed and claimed herein, and the Examiner's proposed combination represents a hindsight reconstruction attempt utilizing the principle of "obvious to try" which is not the standard of 35 U.S.C. 103. Turning to Yamagata et al, applicants note that this

patent issued in 1994, and the disclosure and teachings thereof were available to Otsubo et al, but Otsubo et al disclosed a plasma processing device and plasma processing method not utilizing the disclosure of Yamagata et al therein.

Referring to Yamagata et al at col. 5, line 55 et. seq., there is described that "the anode 12 supplied with the RF power..." and as described in this patent, when the capacitors 24, 26 are controlled under presence of the anode 12, cathode 14 and grid electrode 16, it is possible to control a state in which RF power is supplied between the anode 12 and the grid electrode 16 and a state in which RF power is supplied between the cathode 14 and the grid electrode 16. That is, Yamagata et al discloses that when RF power is supplied between the anode 12 and the grid electrode 16, plasma can perform an isotropic etching and when RF power supply between the cathode 14 and the grid electrode 16, plasma can perform an anisotropic etching. Thus, Yamagata et al discloses a phenomenon that an RF current passes from the anode 12 through plasma and flows to the grid electrode 16 and a phenomenon that the RF current passes from the cathode 14 through plasma and flows to the grid electrode 16. Irrespective of this disclosure in Yamagata et al, applicants submit that Yamagata et al provides no description as to a phenomenon for discharging an electromagnetic wave and that the electromagnetic wave radiating means as defined in claims 1 and 2 includes a radiated electromagnetic wave power control means to control radiated electromagnetic wave power using the radio frequency displacement current control means forming a resonant circuit, which features are also not disclosed by Otsubo et al. Thus, applicants submit that independent claims 1 and 2 patentably distinguish over this proposed combination of references in the sense of 35 U.S.C. 103 and should be considered allowable thereover.

With respect to dependent claim 3 which stands rejected under 35 U.S.C. 103 based upon the Otsubo et al and Yamagata et al in view of Misono et al, applicants

submit that claim 3 is a dependent claim dependent from claims 1 and 2 and as pointed out above, the features of claims 1 and 2 as well as claim 3 are not disclosed by the combination of Otsubo et al and Yamagata et al in the sense of 35 U.S.C. 103. Irrespective of whether or not Misono et al may be considered to have a memory means 18, applicants submit that Misono et al does not overcome the deficiencies of Otsubo et al and Yamagata et al as pointed out above. Applicants further note that col. 4, lines 10-22 of Misono et al, provide that an auxiliary coil is used for forming an auxiliary magnetic field, and a state of plasma distribution density attained by a plasma monitoring means is compared with a density distribution reference state stored in the memory means, with the auxiliary current value flowing in each of the auxiliary coils being calculated so as to cause the plasma in a reaction chamber to have the aforesaid reference distribution and control. Thus, Misono et al concerns a closed loop control in which a distribution controlling method calculates a corrected current value flowing in each of the auxiliary coils on the basis of data obtained from a monitoring means so as to control the plasma distribution. In contradistinction, in accordance with the present invention, a capacitance of a capacitor 11 of a resonant circuit as shown in Fig. 2 of the drawings of this application is controlled and a uniformity in plasma as illustrated in Fig. 6 of the drawings of this application is obtainable. Thus, the present invention relates to an open loop control in which a capacitance of the capacitor is controlled to correspond to a capacitance corresponding to a plasma distribution of a target with the target plasma distribution being realized in the manner defined. As such, it is apparent that Misono et al does not overcome the deficiencies of Otsubo et al and Yamagata et al as pointed out above, and the combination does not provide the claimed features of claims 1 and 2 or dependent claim 3, such that all claims patentably distinguish over this proposed combination of references.

With respect to the features of claims 7 and 8, applicants note that irrespective of the Examiner's position, neither Otsubo et al nor Yamagata et al disclose a RF bias circuit which is floated with respect to ground so as to send RF current to the substrate to be processed as described at pages 27 and 28 of the specification, for example. While the Examiner refers to bias power supply 56 of Otsubo et al, there is no disclosure of the features as claimed in claim 7, noting that in accordance with the present invention, plasma is generated with an electromagnetic wave power and the RF current is flowed in the plasma from the RF power supply 17 which differs from the electromagnetic wave power and both power supplies have different structural arrangements. Moreover, while Fig. 2 of Yamagata et al shows an arrangement which plasma is generated by an electromagnetic wave power and a RF current is flowed from the RF power supply, Fig. 2 merely shows a path where RF current flowing from the table 36 to the plasma returns to the RF power source 50 which is coupled to ground so that it is apparent that there is not provided a RF bias circuit which is floated with respect to ground so as to send RF current to the substrate to be processed as recited in claim 7. Thus, claim 7 also patentably distinguishes over this cited art taken alone or in combination in the sense of 35 U.S.C. 103.

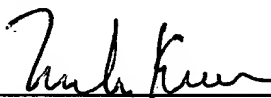
As to claim 8, such claim recites the feature of multiple RF current conducting means installed at a position opposite to a position where the substrate to be processed is mounted, as represented by the electrode 2A and 2B, for example, and that the multiple RF current conducting means are provided with a means to control a ratio of RF current flowing from the substrate to be processed to each of RF current conducting means which feature is described at pages 27-29 of the specification, for example. Applicants submit that neither Otsubo et al nor Yamagata et al disclose the claimed features of claim 8 and, in particular, Yamagata et al does not disclose that a RF current is flowed from the substrate to be processed to the RF

current conducting means which are arranged at a position opposite to a position where the substrate to be processed is mounted. Thus, applicants submit that claim 8 also patentably distinguishes over this proposed combination of references in the sense of 35 U.S.C. 103 and should be considered allowable thereover.

In view of the above amendments and remarks, applicants submit that all claims present in this application should now be in condition for allowance, and issuance of an action of a favorable nature is courteously solicited.

To the extent necessary, applicant's petition for an extension of time under 37 CFR 1.136. Please charge any shortage in the fees due in connection with the filing of this paper, including extension of time fees, to Deposit Account No. 01-2135 (520.39737X00y) and please credit any excess fees to such deposit account.

Respectfully submitted,



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VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE SUBSTITUTE SPECIFICATION:

Page 27, please amend the paragraph beginning at line 8 as follows:

Radio frequency power is applied to the stage electrode 3 from the bias power supply 17 through transformer 29. Radio frequency current passes through the substrate 15 and the plasma, and flows to facing electrodes 2a and 2b. Since the transformer 29 is separated from or is floated with respect to the ground, almost all the radio frequency current flowing from the stage electrode 3 is fed to facing electrodes 2a and 2b, without going to any other places.

Page 28, please amend the paragraph beginning at line 13 as follows:

In this Embodiment, as shown in Figure 8, the output of the bias power supply 17 is separated from or is floated with respect to the ground and is connected through the transformer 29 to the stage electrode 3. A current circuit is provided in such a way that the current can return to the transformer from facing electrodes 2a and 2b through low pass filters 13a and 13b.

IN THE CLAIMS:

Please amend claims 1-3, 7 and 8 as follows:

1. (amended) A plasma processing apparatus to provide plasma processing of a substrate by plasma, said plasma processing apparatus comprising a plasma processing gas supply means, an exhaust means in a plasma process chamber, and a plasma generating means; said plasma generating means further comprises;

a capacitatively coupled discharge means consisting of mutually isolated multiple conductors,

an electromagnetic wave radiating means to cause radio frequency displacement current to flow between said conductors and to emit electromagnetic wave, and

a magnetic field forming means;

wherein said electromagnetic wave radiating means further comprises ~~an~~ a radiated electromagnetic wave power control means to control the radiated electromagnetic wave power through radio frequency displacement current control means forming a resonant circuit.

2. (amended) A plasma processing apparatus to provide plasma processing of a substrate by plasma, comprising ~~a plasma processing gas supply means, an exhaust means in a plasma process chamber, a plasma generating means, and a means to process plasma using the generated plasma; said plasma generating means further comprises~~ ;

a capacitatively coupled discharge means consisting of mutually isolated multiple conductors; and

an electromagnetic wave radiating means to cause radio frequency displacement current to flow between said conductors and to emit electromagnetic wave;

wherein said electromagnetic wave radiating means further ~~comprising an~~ comprises a radiated electromagnetic wave power control means to control radiated electromagnetic wave power using the radio frequency displacement current control means forming a resonant circuit.

3. (amended) A plasma processing apparatus according to Claim 1 or 2 further characterized by ~~comprising a means to store the~~ a processing procedure to control distribution during plasma processing and a means to control plasma distribution according to the processing procedure stored in said ~~memory store~~ means.

7. (amended) A plasma processing ~~system~~ apparatus to provide plasma processing of a substrate by plasma, comprising;

a plasma processing gas supply means,
an exhaust means in a plasma process chamber,
a plasma generating means, and
a means to send RF current to a ~~the~~ substrate to be processed, and
~~a means to process plasma using the generated plasma;~~

wherein said plasma processing ~~system~~ characterized in that apparatus
further includes a RF bias circuit which is floated with respect to ground so as to
send RF current to the substrate to be processed ~~is suspended with respect to the~~
ground.

8. (amended) A plasma processing ~~system~~ apparatus to provide plasma processing of a substrate by plasma, comprising;

a plasma processing gas supply means,
an exhaust means in a plasma process chamber,
a plasma generating means, and
~~a means to send RF current to a substrate to be processed, and~~
a means to process plasma using the generated plasma;

said means to send RF current to a ~~the~~ substrate to be processed further
characterized in that;

multiple RF current conducting means are installed at ~~the~~ a position opposite
to ~~the~~ a position where the substrate to be processed is mounted, and

said multiple RF current conducting means are provided with a means to
control a ratio of RF current ~~ratio by each RF current~~ flowing from the substrate to be
processed to each of the RF current conducting means.



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PLASMA PROCESSING APPARATUS AND PROCESSING METHOD

BACKGROUND OF THE INVENTION

5 [Field of the Invention]

The present invention relates to a plasma processing apparatus, ^{which is} equipped with a plasma generation means, and ^{to a} plasma processing method, ^{and, more particularly, the invention relates} or especially ^{to} plasma etching suited to ^{the} formation of ^a [the] minute pattern ⁱⁿ [of] a
10 semiconductor device and liquid crystal display device and uniform processing of a large-diameter substrate, plasma CVD suited to ^{the} formation of a thin film having a minute structure, ^a plasma processing apparatus for plasma polymerization, and ^a plasma processing method.

15 [Related Background Art]

In ^a [the] plasma processing apparatus ^{of the type} which ^{is used to produce} [processes] ^a semiconductor device and ^a liquid crystal display device, ^{for example,} using ^a plasma, it is ^{a requirement} [required] that the electric characteristics of the semiconductor device ^{be} [is] not ^{be} changed
20 by control and treatment of the radical species affecting the processing performance, ^{the} energy and directionality of ions applied to the substrate to be processed, and ^{the} uniformity in plasma processing.

Regarding the control of radical species generation,
25 Official Gazette of Japanese Patent Laid-Open NO.

195379/1996 discloses a plasma processing method
characterized by excellent ^{controllability of} radical species generation
[controllability is realized] by generation of plasma
containing both capacitatively coupled and inductively
5 coupled characteristics.

Ion energy control and ion directionality are mentioned
in the Official Gazette of Japanese Patent Laid-Open NO.
158629/1985, which discloses a method of electronic
cyclotron resonant discharge and ^{the} application of ^a radio
10 frequency bias to a substrate supporting electrode.
Official Gazette of Japanese Patent Laid-Open NO.
206072/1993 reveals a method of ^{generating an} inductively RF coupled
discharge and application of radio frequency bias to a
substrate supporting electrode. These methods have
15 realized ^{an} improvement ^{in the} of directionality of ions by generation
of high density plasma at a low pressure and ion energy
control by application of ^a radio frequency bias.

Regarding uniformity control, Official Gazette of
Japanese Patent Laid-Open NO. 195379/1996 discloses that
20 a plasma processing technique featuring excellent
controllability of plasma density distribution is realized
by generation of plasma containing both capacitatively
coupled and inductively coupled characteristics.

Furthermore, regarding the control of ^{the} plasma processing
25 uniformity, the Official Gazette of Japanese Patent

Laid-Open NO. 283127/1986 discloses ^{a technique in which} [the art where] the electrode to which radio frequency power is applied is split into multiple pieces, and power applied to each electrode is independently controlled, thereby improving ^{the} uniformity.

5 Official Gazette of Japanese Patent Laid-Open NO. 260596/1999 reveals ^{a technique for} [the art of] ^{the} controlling plasma density distribution by controlling the electromagnetic wave emission distribution.

10 One of the problems in treating a semiconductor device substrate using ^a plasma is that ^{the} electrical characteristics of the semiconductor device ^{are} [is] changed by electrical influence during plasma processing. Official Gazette of Japanese Patent Laid-Open NO. 3903/2000 ^{discloses a technique for} [shows an art of] ^{the} reducing ^{the} influence of plasma processing ~~on~~ ^A electrical characteristics.

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To satisfy processing characteristics required for production of a semiconductor device and liquid crystal display device, mere ion energy control is not sufficient. Processing characteristics are greatly affected by radical species, and its general control method is to change the processing conditions, such as ^{the} plasma generating radio frequency power and pressure in the process chamber.

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However, radical species control based on processing conditions is limited, and differences in processing performances cannot be covered merely by changing the

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processing conditions if the discharge method is different, as in the case of the electronic cyclotron resonant method, inductive RF coupled method, and ^{the} most popular parallel plate electrode method mentioned as prior art.

5 Thus, problems remain ⁱⁿ that ^{the} processing performances realized by ^{the} parallel plate electrode method cannot be realized by ^{the} electronic cyclotron resonant method, inductively RF coupled method, etc.

10 The electronic cycrotron resonant method allows effective acceleration of electrons to be achieved by resonance. ^{Thus, the} [So] ^{the} electron energy level is high, and processing is difficult when decomposition of ^{the} process gas is reduced. In the inductively RF coupled method, plasma of locally high density is formed by electromagnetic waves radiated from the antenna, and ^{it} is diffused upward. ^{Thus, the} [So] ^{the} electron energy level at ^{the} plasma generating portion is high, and ^{the} processing is difficult when decomposition of ^{the} process gas is reduced.

15 In the parallel plate method, by contrast, electrons ^{are} [is] accelerated on the sheath formed on the electrode surface and interface of ^{the} plasma, and ^{the} energy level is low. ^{Thus,} [So] ^{the} this method is suited to processing under the conditions where process gas decomposition is reduced.

20 As described above, ^{the} electron acceleration mechanism in plasma is different depending on the discharge method, and this is the reason why the differences in performances

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of each method cannot be covered by processing conditions.

Another problem is how to ensure uniform processing of all^{of} the substrates. To improve productivity, the diameter of the substrate to be processed has been increased from 150 mm to 200 mm, and the diameter tends to increase to 300 mm. According to the prior art, uniformity has been achieved by changing the processing conditions or by taking such similar means.

However, ^achange ⁱⁿ [of] processing conditions is insufficient, as described above, but this is one of the important means to control the radical species. This makes it necessary to ensure a uniformity^{of} control [means] which ensures compatibility between processing conditions which implement optimum etching characteristics and film formation characteristics and uniformity in processing.

The ^{techniques} [prior arts] revealed in [said] Official Gazette of Japanese Patent Laid-Open NO. 195379/1996 and Official Gazette of Japanese Patent Laid-Open NO. 283127/1986 are not sufficient in ^{connection with the} mutual independence between uniformity in plasma processing and ^{the} control of radical species generation, and ^{in connection with the} compatibility between uniformity control and low pressure processing. Furthermore, ^{the} plasma density distribution control method ^{as} disclosed in the Official Gazette of Japanese Patent Laid-Open NO. 260596/1999 is not sufficient in ^{the} plasma distribution control range. These

are the problems of the prior art.
The electric characteristics of semiconductor devices change when plasma is used to process these semiconductor device substrates due to [the] electric influence during plasma processing. This problem is caused by an uneven self-bias potential occurring to the sheath between the substrate under processing and plasma.

To control ion energy, radio frequency power is applied to the substrate supporting electrode. One of the major reasons for uneven self-bias potential is that radio frequency current distribution resulting from application of this radio frequency power becomes uneven on the substrate.

The self-bias potential control method disclosed in [said] Official Gazette of Japanese Patent Laid-Open NO. 3903/2000 cannot control the self-bias potential distribution, and is insufficient to reduce the changes in electric characteristics.

Furthermore, higher integration of semiconductor devices and greater diameter of the substrate for production have made it necessary to develop a technique providing a better controllability than prior art, e.g. higher selectivity with underlying material, higher performance in processed shapes, more uniform processing of large-diameter substrates, and less influence upon device

characteristics.

Regarding uniformity in plasma processing, the following trend ^{has been} ~~is~~ observed. As a result of ^{the} increased diameter of the substrates to be processed, the process gas for etching and CVD processing flows from the center of the substrate to the outer periphery, and ^{the} radical species concentration distribution and ^{the} deposition film distribution become apparent. This makes it difficult to ensure uniform processing on all surfaces of the large-diameter substrate.

To solve these problems, the factors disabling uniform distribution must be offset by other etching characteristic controlling factors. One of the controlling factors is the capability of adjusting ^{the} plasma distribution as a convex/concave distribution, independently of processing conditions, such as plasma generation power and pressure.

Radical species ^{are} ~~is~~ generated by collision between process gas and electrons ⁱⁿ plasma, and ^{it} is one of the factors which greatly affect the processing characteristics, such as selectivity, processed shape and film quality in etching and CVD processing by plasma. The generated volume and type of this radical species is determined by the status of ^{the} energy of ^{the} electrons ⁱⁿ plasma.

Furthermore, to protect against the influence of plasma processing upon ^{the} semiconductor device, distribution of the

RF current flowing through the substrate must be controlled in order to control ^{the} self-bias potential distribution.

SUMMARY OF THE INVENTION

5 One ~~of the~~ object of the present invention is to realize a plasma processing apparatus and processing method which have a wide control range for the status of electron energy, independently of processing conditions and uniformity control, and which are capable of controlling radical species generation.

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 Another object of the present invention is to realize a plasma processing apparatus and processing method comprising a uniformity control means capable of ~~(Controlling)~~ ^{controlling} independently ~~of~~ processing conditions, such as plasma generation power and pressure, said uniformity control means providing compatibility of plasma uniformity with radical species control, ion energy control and improved ion directionality by generation of low pressure/high density plasma.

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20 A further object of the present invention is to realize a plasma processing apparatus and processing method comprising a means ~~of~~ ^{for} controlling the distribution of RF current flowing through the substrate, said means providing compatibility among plasma uniformity, radical species control, ion energy control and improved ion

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directionality.

To achieve said objectives, the present invention has the following arrangement:

(1) A plasma processing apparatus comprises a plasma processing gas supply means, an exhaust means in a plasma process chamber, a plasma generating means, and a means to process plasma using the generated plasma; said plasma generating means^{being} characterized by further comprising an electromagnetic wave radiating means^{formed} by displacement current and magnetic field forming means. Said electromagnetic wave radiating means further comprises a means [of]^{for} controlling the radio frequency displacement current flowing between the conductors by forming from each of multiple insulated conductors the electrode of said capacitatively coupled discharge means to which RF voltage is applied.

(2) A plasma processing apparatus comprises a plasma processing gas supply means, an exhaust means in a plasma process chamber, a plasma generating means, and a means [of]^{for} applying RF power to control the energy of ions^a applied to [the]^a substrate placed on [the]^a stage, wherein the facing electrode through which RF [power] current due to said radio frequency power flows via^{the} plasma is composed of multiple insulated conductors, and a means is provided to [make]^{vary} [variable] the impedance between these conductors and ground.

(3) A plasma processing apparatus comprises a plasma processing gas supply means, an exhaust means in a plasma process chamber, a plasma generating means, and a means of ^{for} applying RF power to control the energy of ions [^] applied to the substrate placed on the stage. Said plasma processing apparatus further comprises a stage for applying said radio frequency power and a means of keeping the facing electrode separated from the ground, wherein RF current due to application of radio frequency power flows through said facing electrode via plasma.

(4) For uniformity, plasma distribution is controlled by controlling the distribution of the radiated electromagnetic wave power and controlling the radio frequency power supplied to ^{the} plasma in a capacitatively coupled state from multiple conductors to which radio frequency power is applied.

The mechanism ^{for} giving energy to the electrons ^{the} in plasma from ^{the} electric field of electromagnetic waves [^] includes a method of direct acceleration in the electric field of electromagnetic waves ^{the} by increasing [^] electromagnetic wave power (IPC: inductively coupled plasma). Another method included in said mechanism is to accelerate electrons by matching between the direction in which electrons are rotated by the magnetic field and the direction of the electric field of electromagnetic waves [^] by application of ^a

magnetic field (electron cyclotron resonance).

Energy is supplied by the former method when^a magnetic field is not applied. When^a magnetic field is applied, an electromagnetic wave passes through plasma more easily, and energy is supplied by the latter method.

When^{the} magnetic field is applied, the direction of electron motion is matched with the direction of the electric field of electromagnetic waves, if the frequency at which electrons are rotated by^{the} magnetic field are matched with the frequency of electromagnetic waves (electron cyclotron resonant conditions). Accordingly, electrons are (kept) accelerated until they collide with gas molecules, thereby creating high energy. If magnetic field conditions disagree with electron cyclotron resonant conditions, the direction of electron motion gradually disagrees with the direction of the electric field of electromagnetic waves, and acceleration and deceleration of electrons are repeated.

As the magnetic field conditions disagree with electronic cyclotron resonant conditions, the maximum energy reached by^{the} electrons is reduced. ^{The} Electron energy becomes lower than that under electronic cyclotron resonant conditions.

As described above, control of the magnetic field conditions allows free control of^{the} electron energy. This

makes it possible to control the generation volume and type of the radical species produced by decomposition of process gas.

In the event of disagreement with resonant conditions, the maximum energy reached by electrons has the following relationship. The percentage of reduction of the maximum energy of ^{the} electrons with respect to the percentage of disagreement of magnetic field conditions with the resonant conditions increases in direct proportion to ^{the} electromagnetic wave frequency. Under the conditions of 2.45 GHz, which is normally used, there is a sharp reduction of electron energy due to deviation from the electronic cyclotron conditions, and practical control is difficult. ^A Practically controllable frequency range is from 200 MHz to 10 MHz.

Electron cyclotron resonance at a frequency of several tens of MHz to 300 MHz is disclosed in Oda, Noda, and Matsumura (Tokyo Institute of Technologies): Generation of Electron Cyclotron Resonance Plasma in the VHF Band: JJAP Vol.28, No.10, October, 1989 PP.1860-1862, and Official Gazette of Japanese Patent Laid-Open NO.318565/1994. The relationship between the state of electron energy and magnetic field strength is not described therein.

A means to emit electromagnetic waves was arranged in such a way that ^a displacement current was fed between

insulated conductors and^{an} electromagnetic wave is radiated by this displacement current. A resonant circuit having the same resonant frequency as the radio frequency to be applied, including the capacity formed between conductors, was formed between the conductors. Thus, resonant conditions were controlled, thereby controlling the displacement current and radiated electromagnetic wave power.

Multiple RF current conducting means are installed at the position opposite to the position where the substrate to be processed is mounted to ensure that control^{of} the RF current ratio flowing through said multiple RF current conducting means^{will be possible}.

When there is no magnetic field,^{an} electromagnetic wave^{will} hardly progress in^{the} plasma. Under this condition without^a magnetic field, conditions close to resonance conditions are setup, and^{the} radiated electromagnetic wave power is increased, thereby ensuring energy to be supplied^{to} electrons in^{the} plasma from^{the} electromagnetic waves^{are} at a position close to where^{the} electromagnetic waves^{are} radiated. Under these conditions, electron energy becomes partially high at a position close to where^{the} electromagnetic waves^{are} radiated, and decomposition of^{the} process gas proceeds. This makes it difficult to^{effect} control at the state of low dissociation.

Under the condition where^a magnetic field is applied,

electromagnetic waves^{are} [is] likely to progress in^{the} plasma. This allows energy to be supplied from electromagnetic waves into^{the} electrons^{the} in plasma over the entire space where plasma is generated. This leads to uniform distribution of electronic energy. Furthermore, ^{the} electron energy level is also made low, and control is ^{affected} [made] in the state of low dissociation.

As under the condition without^a magnetic field, if energy is supplied at a position close to where electromagnetic waves^{are} [is] radiated, ^a high density plasma is formed in this portion, and diffusion from this position allows plasma to reach the substrate to be processed. In such a mechanism, therefore, diffusion is changed by pressure, and^{the} plasma density and^{the} plasma distribution on the substrate to be processed is affected by pressure.

By contrast, when^a magnetic field is applied and energy is supplied over the entire space where plasma is generated, they are not affected by diffusion of^{the} plasma. So^{the} plasma distribution is not easily affected by processing conditions, such as pressure. Such conditions are essential to control processing conditions and plasma distribution independently.

As^a means of controlling^{the} uniformity according to the present invention, multiple portions were provided where electromagnetic waves^{were} [was] radiated by^a displacement current,

an arrangement was made to ensure that the amount of radiated electromagnetic waves could be controlled at least one of said portions. The resonance conditions control method described above is used for this control. The portion radiating electromagnetic waves is provided in a double configuration to have a circular form, ^{so that the} (then) plasma distribution can be controlled as a convex/concave distribution by controlling each radiated electromagnetic wave.

10 Furthermore, when the magnetic field is applied, plasma is generated over the entire plasma generation space. Then changes ^{in the} [of] plasma distribution are less often caused by processing conditions, and plasma distribution control by control of resonance conditions can be ^{effected} [made] independently of processing conditions. Also, the generated volume and type of the radical species can be controlled by ^a magnetic field, independently of the uniformity control and processing conditions.

20 If the conductor portion radiating electromagnetic waves is provided close to ^{the} plasma, ^{the} power can be supplied to plasma by capacitative coupling. Therefore, ^{accordance with} in the present invention, discharge can be made by the same capacitative coupling as that of the parallel plate electrode method under the conditions where resonant circuit current is reduced without ^{the} magnetic field being

applied. ^{an}Inductively coupled discharge due to
electromagnetic wave emission is caused by increasing the
resonant circuit current, and ^adischarge under electron
cyclotron resonance conditions can be caused by application
5 of ^amagnetic field.

^ACapacitatively coupled discharge, inductively coupled
discharge and electronic cyclotron discharge each have
different states of electron energy and different states
of process gas decomposition. The present invention allows
10 radical species to be controlled by controlling the
discharge method, in addition to radical species control
by magnetic field ^{as}described above.

The energy of the ions applied to the substrate placed
on the stage is controlled by application of radio frequency
15 power. Radio frequency current by this radio frequency
power is fed to the facing electrode through ^{the} plasma.

To solve the problem that electric characteristics of
the semiconductor device ^{and} ~~(is)~~ changed by electric influence
during plasma processing, this facing electrode is composed
20 of multiple insulated conductors, and the radio frequency
current flowing through the substrate mounted on the stage
is made uniform by optimization of ^{the} impedance between these
conductors ^aand ground. This has ensured ^auniform
distribution of self-bias potential on the substrate, and
25 has reduced changes in ^{the} electric characteristics of the

semiconductor device resulting from electric influence during plasma processing.

Also, the stage and facing electrode through which radio frequency current flows via ^{the} plasma are kept separated from the ground. This greatly reduces the percentage of radio frequency current flowing from the stage into ^{the} plasma by application of radio frequency power, with respect to that flowing to the conductor connected to the ground other than ^{the} facing electrode.

10 This allows almost all radio frequency currents to flow between the stage and ^{the} facing electrode. Also, ^{the} radio frequency current on the stage can be made uniform by installing the facing electrode parallel with the stage. This can reduce changes in electric characteristics of the semiconductor device resulting from electric influence
15 during plasma processing.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic ^{diagram} ~~(drawing)~~ representing a plasma processing apparatus ^{representing a} ~~(in the)~~ first Embodiment according to the present invention;

Figure 2 is a ^{schematic circuit diagram} ~~(drawing)~~ representing a resonant circuit model in the first Embodiment according to the present invention;

25 Figure 3 is a ^{graph} ~~(drawing)~~ representing a plasma density

distribution control in the first Embodiment according to the present invention;

Figure 4 is a ^{graph} ~~(drawing)~~ representing a plasma density distribution control in the first Embodiment according to the present invention;

Figure 5 is a ^{graph} ~~(drawing)~~ representing a plasma density distribution control in the first Embodiment according to the present invention;

Figure 6 is a ^{graph} ~~(drawing)~~ representing the relationship between variable capacitor capacity and plasma density distribution uniformity in the first Embodiment according to the present invention;

Figure 7 is a ^{diagram showing} ~~(drawing representing)~~ a radio frequency current path model based on application of radio frequency bias in the prior art;

Figure 8 is a ^{diagram showing} ~~(drawing representing)~~ a radio frequency current path model based on application of radio frequency bias in the first Embodiment according to the present invention;

Figure 9 is a ^{diagram} ~~(drawing)~~ representing the arrangement of a cover member in the first Embodiment according to the present invention;

Figure 10 is a ^{diagram} ~~schematic (drawing)~~ representing a plasma processing apparatus ^{representing a} ~~[in the]~~ second Embodiment according to the present invention; and

Figure 11 is a ^{processing time diagram} schematic drawing ^{the} representing ^a progress of etching in the second Embodiment according to the present invention.

5 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

^{A first} One Embodiment of the present invention will be described with reference ^{Figs. 1-9 of} to the attached drawings. Figure 1 is a schematic ^{diagram} drawing of a plasma processing apparatus ^{representing} as the first Embodiment.

10 A process chamber 1 comprises inner wall surfaces 1a and 1b, and both inner wall surfaces are insulated ^{from each other} by an insulator 4c. Facing electrode 2a ^{disposed in} and 2b and stage electrode 3 are ^{relation} placed therein face-to-face with each other. The ^{inner wall surfaces 1a and 1b} are insulated from ^{the} facing electrode 2b by an insulator 4a ^{an} and from ^{the} stage electrode 3 by ^{an} the insulator (not illustrated). The facing electrodes 2a and 2b are insulated from each other by an insulator 4b.

Connections between the inner wall surface of the process chamber 1, ^{the} electrodes ^{the} and ^{the} insulators are vacuum sealed. 20 Refrigerant flow paths 5a and 5b, and process gas supply paths 6a and 6b are provided inside the facing electrode. Refrigerant flow paths 5a and 5b are connected to ^{the} a circulator (not illustrated) to ensure that the facing electrode temperature ^{will} can be kept at ^a the set value.

25 Process gas supply paths 6a and 6b are connected to

the process gas supply source 27 so that process gas (of) ^{at} the set flowrate can be supplied. Covers 8a, 8b, 8c and 8d are mounted on the surface of the facing electrode, and each cover ^{forms} ^{with the adjacent cover} [has] a space of 0.2 mm.

5 Process gas is supplied to the back of ^{the} covers 8a, 8b and 8c through gas inlets 7a and 7b from process gas supply paths 6a and 6b. Passing through the 0.2 mm space between covers, ^{the gas} (it) is fed to the process chamber 1.

10 The inner wall surface 1a is connected with a radio frequency power supply 18 and matching box 19. It is also connected with a high pass filter 20 in conformity to ^{the} frequency of the radio frequency power supply 9, so that radio frequency current from radio frequency power supply 9 is fed to the ground.

15 Facing electrode 2a is connected with radio frequency power supply 9 through matching box 10 and variable capacitor 11, and facing electrode 2b is connected with radio frequency power supply 9 through matching box 10 and inductors 12^a and 12b.

20 Facing electrodes 2a and 2b are connected with low pass filters 13a and 13b in conformity to the frequency of ^{the} bias power supply 17, so that radio frequency current from the bias power supply 17 applied to the stage electrode 3 can be fed to a transformer 29 through facing electrodes 2a
25 and 2b.

A coil 14 is provided on the outer periphery of the process chamber 1 so that ^a magnetic field intersecting at right angles with the facing electrodes 2a and 2b is formed in the process chamber.

5 A substrate 15 can be mounted on ^{the} stage electrode 3. It is chucked on the surface of ^{the} stage electrode 3 by ^{the} an electrostatic chucking unit (not illustrated), and refrigerant is supplied from a circulator 16 to a temperature controller (not illustrated) to permit control of the
10 temperature of the substrate 15 during plasma processing.

 Furthermore, a stage electrode 3 is connected with a bias power supply (2 MHz) 17 through transformer 29 in order to control the energy of ^{the} ions applied to the substrate during plasma processing. A transformer 29 is ^{the} kept separated from
15 the ground to reduce ^{the} capacitive component with the ground. The outer periphery of the stage electrode 3 is composed of a member connected to the ground.

 The interior of the process chamber 1 is arranged to be exhausted to the state of vacuum by an exhaust controller
20 24 and ^{the} exhausting capacity can be adjusted and ^{the} pressure can be adjusted to the set value. A monitor 25 is installed in the process chamber 1 to monitor the progress of plasma processing.

 A variable capacitor 11 has its capacity value
25 controlled by a drive motor 26 controlled by distribution

controller 28.

✓ The following ^{description provides} ~~describes~~ an example of ~~[example in]~~ etching ^{carried out in} as the first Embodiment of the present invention. A substrate 10 is inserted into the ^{plasma chamber} ~~[stage electrode 3]~~ and ^{on the stage electrode 3} is placed ~~[therein]~~. Etching gas (carbon fluoride based gas) of the set flowrate is fed from an etching gas supply source 27, and ^{the} exhaust is controlled so that pressure in the process chamber will be 1 Pa.

Etching gas is supplied to the back of covers 8a and 8b from process gas supply paths 6a and 6b through gas inlets 7a and 7b. To feed gas to the process chamber 1 through the 0.2 mm space between covers, the pressure on the back of ^{the} covers is increased and ^{the} covers are cooled by facing electrodes 2a and 2b.

15 A ^a Silicon oxide film as an insulator of ^a semiconductor device and ^a silicon film are formed on the substrate. This substrate is electrostatically ^{sucked} ~~[sucked]~~ on the stage electrode 3, and helium gas is supplied between the substrate and stage electrode 3 from a helium gas supply source (not 20 illustrated), thereby reducing ^{the} thermal resistance from the substrate to the stage electrode 3 and avoiding ^a rise ~~[of]~~ ^{in the} temperature ~~[in]~~ ^{of} the substrate being etched.

From the radio frequency power supply 9, 100 MHz, 2000 W radio frequency power is applied to the facing electrodes 25 2a and 2b, and plasma is generated by capacitatively coupled

discharge.

First~~ly~~, [the following describes] the principle of emission of electromagnetic waves from the outer periphery of the insulator 4a^a will be described.

5 When radio frequency power is supplied to the facing electrode, radio frequency potential occurs ^{on} (to) the facing electrode 2b. Since ^{the} inner wall surface 1a is connected to the ground through a bypass filter, radio frequency displacement current flows to the facing electrode 2b and
10 inner wall surface 1a. This displacement current is fed through the insulator 4a, so electromagnetic waves ^(is) ^{and} radiated by this radio frequency displacement current [and] [electromagnetic wave is radiated] into the process chamber 1 through the space between the covers 8c and 8d.

15 Next, emission of electromagnetic waves from the insulator 4b on the inner periphery will be explained.

 The insulator 4b between facing electrodes 2a and 2b is formulated ^{as} into a model by means of a capacitor. A resonant circuit ^{as} shown in Figure 2 is formed by this capacitor 4c, variable capacitor 11, and inductors 12a and 12b. ←

20 When the capacity of the variable capacitor 11 comes close to the resonant conditions, a greater amount of radio frequency current flows to this circuit. When the capacity of the variable capacitor 11 fails to meet the resonant
25 conditions, the radio frequency current flowing to this

circuit is reduced.

As described above, displacement current flowing to the insulator 4b can control the variable capacitor 11, and electromagnetic waves ^{are} ~~(f)~~ radiated in direct proportion to ^{the} radio frequency displacement current flowing to insulator 4b. Furthermore, electromagnetic waves ^(f) ~~(s)~~ ^{are} radiated into the process chamber 1 through the space between covers 8b and 8c. The electromagnetic wave emission power can be controlled by controlling ^{the} radio frequency displacement current flowing to the resonant circuit using the capacity of the variable capacitor 11.

The density of the plasma generated from electromagnetic waves radiated from the insulator 4a on the outer periphery exhibits a convex distribution with ^a high outer periphery, similar ~~to~~ to the plasma distribution 51 shown in Fig. 3. ^{the} Density of the plasma generated electromagnetic waves radiated from the insulator 4b on the inner periphery exhibits a concave distribution with a high central portion, similar ~~to~~ to the plasma distribution 52 shown in Fig. 3.

The overall plasma distribution is obtained by superimposing the distribution of the plasma resulting from electromagnetic waves radiated from this outer periphery over that resulting from electromagnetic waves radiated from the inner periphery. ^a Uniform plasma can be formed by

adjusting the power of electromagnetic waves radiated from the inner periphery, where plasma density distribution in the vicinity of the substrate 15 within the range from 300 mm is within $\pm 5\%$, as in the case of plasma density distribution 53.

If the power of electromagnetic waves radiated from the inner periphery is reduced, the density of plasma generated from electromagnetic waves radiated from the inner periphery is reduced as in the case of plasma density distribution 54 shown in Fig. 4. Overall plasma density distribution exhibits a convex distribution, as shown in plasma density distribution 55.

If the power of electromagnetic waves radiated from the inner periphery is increased, the density of plasma generated from electromagnetic waves radiated from the inner periphery is increased, as in the case of plasma density distribution 56 shown in Fig. 5. Overall plasma density distribution exhibits a concave distribution, as shown in plasma density distribution 57.

Figure 6 shows the relationship between the capacity of variable capacitor 11 and uniformity of plasma density.

Any increase of the capacitor capacity causes plasma density distribution to be changed from convex to flat, then to concave distribution, showing that plasma density distribution can be controlled by the capacity of the

variable capacitor 11.

The capacity of the variable capacitor 11 is controlled
[by control] from the distribution controller 28 and drive
motor 26. Such control is also possible during etching.

5 When^a magnetic field is not formed, ^{the} electromagnetic waves
^{are} reflected by ^{the} generated plasma, and ^{the} influence on ^{the} plasma
is small. In this case, ^{that the} discharge is ^a mostly capacitatively
coupled discharge, so ^{the} electron energy distribution of ^{the}
plasma is close to ^{the} Maxwell-Boltzmann distribution.

10 When^a magnetic field is formed, current is fed to coil
14 to form ^{the} magnetic field. This magnetic field is formed
almost in conformity to the direction of said
electromagnetic wave emission. In the vicinity where
electron cyclotron resonance (35G ($35 \times 10^{-4}\text{T}$)) is caused
15 by ^{the} magnetic field strength with respect to the frequency
^{the} of radiated electromagnetic waves, energy is supplied to ^{the}
electrons ^{the} in plasma more effectively ^{than simply from the} [that] electromagnetic
wave electric field, thereby allowing ^{the} electron energy to
be increased.

20 At 100 MHz electron cyclotron resonance, as in the case
of the first Embodiment of the present invention, the
rotating angular velocity of the electrons is reduced in
direct proportion to ^{the} electromagnetic wave frequency,
compared with ^{the} electron cyclotron resonance due to ^a
25 conventional 2.45 GHz microwave. However, the electric

field of the electromagnetic wave accelerating electrons^A remains unchanged if the power density is the same, without depending on frequency. The same energy can be given to^{the} electrons.

5 If^{the} frequency is low, ^{the} angular velocity is reduced, so^{that a} disagreement between^{the} cyclotron frequency due to^{the} magnetic field and^{the} frequency of^{the} electromagnetic waves occurs. This increases^{for} tolerance in exchange^A [of] energy. In the case of 100 MHz, for example, electrons can be accelerated to the
10 level required for ionization and generation of radical species in a wide range of magnetic field strength from 10G ($10 \times 10^{-4}T$) to 70G ($70 \times 10^{-4}T$).

In this case, the maximum energy of^{the} electrons to be accelerated is reduced with increasing departure from
15 electronic cyclotron conditions, making it possible^{to} control the state of electron energy^{according to the} [by] magnetic field strength. Namely, ^{the} electron energy can be changed from^A [the] level suited to generation of the radical species up to the level of ionization by changing the magnetic field strength.

20 In the first Embodiment according to the present invention, ^{the} magnetic field strength is set to 50G ($50 \times 10^{-4}T$), which is higher than^{the} electronic cyclotron condition. The condition is set to the state where the maximum electron energy is reduced.

25 Such an effect is measured because^{the} electromagnetic wave

frequency is within the range from 200 MHz to 10 MHz. Easy use and excellent effects can be ensured especially within the range from 100 MHz to 50 MHz. If the electromagnetic wave frequency is 200 MHz, the range where there is an effect of controlling the state of electron energy by ^{the} magnetic field strength is reduced in inverse proportion to the frequency, ^{that} so, this range is up to about 100G ($100 \times 10^{-4}T$). In the case of 10 MHz, the effect of ^{the} magnetic field can be measured when ^{the} magnetic field strength is about 2G ($2 \times 10^{-4}T$) or more.

When 2 MHz radio frequency power of 1000W is supplied to a stage electrode 3 from the bias power supply 17, the voltage of 700Vpp appears, and ion ^{the} from plasma ^{are} [is] accelerated by this voltage. It is applied to ^{the} substrate 15. Etching gas (carbon fluoride based gas) decomposed by ^{the} plasma with the aid of ion ^{the} reacts with ^{the} silicon oxide film and silicon film on the back of the substrate 15, and etching takes place.

^{the} If ^{the} electron energy level is high, decomposition of carbon fluoride based gas takes place and ^{the} fluorine based radical species increases in number, resulting in ^{an} improved etching rate of silicon film. In an advanced state of gas decomposition, the cross section geometry of ^{the} etching shows an almost vertical shape. If decomposition does not proceed, a forward tapered shape tends to be produced.

In the production of a semiconductor device the etching rate of the silicon film with respect to that of the silicon oxide film as an insulator must be minimized, and the cross section geometry of etching must be made as close as possible to a vertical shape. This requires an adequate control of the decomposition of ^{the} carbon fluoride based gas. It is also necessary to find [out] a condition which ensures compatibility between the two.

When electromagnetic waves ^{are} [is] not radiated (magnetic field: OT), decomposition of ^{the} etching gas does not proceed, and etching is performed to produce a forward tapered shape. If the magnetic field strength is increased, gas decomposition proceeds and a nearly vertical ^{shape} is formed. At the same time, ^{as the} etching rate increases, so the etching velocity ratio increases conversely. It drops suddenly when a condition to promote further decomposition is established.

As described above, decomposition of this carbon fluoride based gas can be controlled by changing the magnetic field, according to the present invention. The present invention makes it possible to optimize [such] ^{such the} etching characteristics ^a as etching velocity ratio between ^a silicon oxide film and ^{the} silicon film, and ^{the} etching shape.

Furthermore, optimization of the etching characteristics can be controlled by the magnetic field,

independently of process conditions, such as pressure, etching gas flowrate and radio frequency power. This allows process conditions to be determined by fine processing, processing velocity and such related factors, resulting in an expanded margin of processing.

Radio frequency power is applied to the stage electrode 3 from the bias power supply 17 through transformer 29. Radio frequency current passes through the substrate 15 and ^{the} plasma, and flows to facing electrodes 2a and 2b. Since the transformer 29 is kept separated from the ground, almost all the radio frequency current (^{flowing} lowing) from the stage electrode 3 is fed to facing electrodes 2a and 2b, without going to any other places.

The radio frequency bias current path controlling the energy of ions applied ^{to} to this substrate 15 is formulated into a model [^] l and is shown in Figure 7 as a normal path. Figure 8 shows the path of this Embodiment. The difference between the two will be discussed below.

In the normal arrangement, ^{one} out of the outputs from bias power source 17 connected to the stage electrode 3 is connected to the ground, as shown in Figure 7. The radio frequency voltage output terminal is connected to the stage electrode 3. Passing through substrate 15, radio frequency current is fed to the facing electrodes 2a and 2b and to the inner wall 1a of the process chamber through ^{the} by plasma.

Passing through the ground, it goes back to the bias power supply 17.

On the outer periphery of stage electrode 3, radio frequency current can flow to both the facing electrode 2b and inner wall 1a of the process chamber. ^{Thus, the} ~~(So)~~ current path impedance is reduced to facilitate ^{the} flow of radio frequency current, and ^{the} density of the radio frequency current flowing through the substrate 15, ^{exhibits} ~~(shows)~~ a distribution ^{which is} high on the outer periphery and low at the central portion. This is one of the biggest causes for changes ^{in the} ~~(of)~~ characteristics when the semiconductor device substrate is processed.

In this Embodiment, as shown in Figure 8, the output of the bias power supply 17 is ~~(kept)~~ ^{and is connected} separated from the ground ^{transformer} through the ~~(transistor)~~ 29 ~~(and is connected)~~ to the stage electrode 3. A current circuit is provided in such a way that the current can ^{return} ~~(go back)~~ to the transformer from facing electrodes 2a and 2b through low pass filters 13a and 13b.

If an arrangement is made to reduce ^{the} capacitive component between the current circuit for the current to ^{return} ~~(go back)~~ to the transformer and ground, the current flows from the stage electrode 3 to the inner wall 1a of the process chamber, and ^{the} impedance of the path for the current to ^{return} ~~(go)~~ ^{back} to the transformer is increased. Thus, radio frequency current flowing through this path is greatly reduced.

Therefore, ^{the} radio frequency current flowing from the stage electrode 3 mostly flows to the facing electrodes 2a and 2b.

As a result, parallel installation of ^{the} stage electrode 3 and ^{the} facing electrodes 2a and 2b makes ^{the} radio frequency current distribution almost uniform. This leads to a substantial relief of the problem that electric characteristics of the semiconductor device are much changed by electrical influence during plasma processing.

10 ^{the} Impedance of ^{the} bias power supply 17 to frequency can be made variable by shifting the characteristics of ^{the} low pass filters 13a and 13b with respect to ^{the} frequency of bias power supply 17.

15 If the low pass filter 13a is set so that ^{the} impedance is minimized and the impedance of low pass filter 13b is set to a value higher than that, ^{the} radio frequency current passing through the substrate 15 will exhibit a distribution where ^{the} current density is high at the central portion and is low on the outer periphery. If setting of the low pass
20 filter impedance is reversed, ^{the} distribution will show that ^{the} current density is high on the outer periphery and low at ^{the} central portion.

As described above, ^{the} optimization of the impedance of ^{the} low pass filters 13a and 13b allows ^{for} more uniform control
25 of ^{the} self-bias potential distribution occurring ^{at} (to) the

substrate 15, and further reduces the changes in the electric characteristics of the semiconductor device due to plasma processing.

Furthermore, if ^{the} low pass filters 13a and 13b are
5 controlled by the drive motor and distribution control
similarly ^{effected} to the variable capacitor 11, then control can
be ^{made} to reach the optimum state where changes in ^{the} electric
characteristics of the semiconductor device do not occur
with respect to changes ⁱⁿ of processing conditions and changes
10 ⁱⁿ (of) the state during processing.

When etching is continued, a deposition film is formed
on the inner wall surface of the process chamber 1. This
film will ^{eventually become} ^{thickly} separated to produce dust. Since ions ^{are} from ^{the}
plasma ^{is} applied to the facing electrodes 2a and 2b at
15 an increased velocity by the radio frequency power to be
applied, a deposition film does not stick to the surface
of the electrode, and ^{so} no dust is produced. When 400 kHz
radio frequency power is supplied from the radio frequency
power supply 18 to the inner wall surface 1a, radio frequency
20 current flows to the inner wall surface 1b connected to
the ground through ^{the} plasma and the outer periphery of the
stage electrode 3. ^A deposition film can be prevented from
attaching onto the inner wall surface by accelerating
entering the inner wall.

25 Covers 8a to 8d are made of silicon, and the effect

differs according to the silicon resistance. The case of using [a] silicon having a high resistance has been mentioned in the Embodiment discussed above.

When [a] low-resistance silicon is used, ^a displacement current flowing between the facing electrodes 2a and 2b does not flow through the insulator 4b due to [a] ^{the} limited space of 0.2 mm between ^{each of the} covers 8a to 8d. It flows mainly between covers 8b and 8c. Radio frequency displacement current flowing between the facing electrode 2b and process chamber 1a flows mainly between covers 8c and 8d.

When the space between covers is ^{so as to be} set ^{the} inclined with respect to magnetic field, displacement current flows in the direction at a right angle to the inclined surface, and electromagnetic waves are radiated in the inclined direction of the space, as shown in the Figure.

A sheath is formed between the cover and ^{the} plasma when plasma is generated, and electromagnetic waves radiated in an inclined direction with respect to ^{the} magnetic field are divided into two components; a component which proceeds along the magnetic field in ^{the} plasma, and a component which travels through the sheath.

^{the} Electromagnetic waves traveling through the sheath proceed gradually in the direction of ^{the} magnetic field, so ^{that the} electromagnetic waves exhibit ^a a flat distribution as compared to the case where electromagnetic waves ^{are} ^{is} radiated ^{in a direction}

parallel with ^{the} magnetic field. If this property is utilized, ^a
uniform plasma can be formed even when ^{the} electromagnetic wave
radiating portion is arranged in a single ring electrode
structure. However, this does not allow electric control
of ^{the} plasma distribution.

Even when the electromagnetic wave radiating portion
is, ^{provided the form of} ~~made~~ in a double ring electrode arrangement, there is
an effect of improving ^{the} distribution controllability,
because ^a flat distribution is ensured for both the plasma
generated by electromagnetic waves ^{from the electromagnetic}
wave radiating portion on the inner periphery and the plasma
generated by electromagnetic waves ^{from the electromagnetic}
wave radiating portion on the outer periphery.

Furthermore, ^{although} covers 8a to 8d are split parts in the
present Embodiment; ^{however}, it should not be understood
that the present invention is limited only to ^{that configuration} them. Figure
9 shows the structure of covers ^{in accordance with} another Embodiment. This
cover 30 has quartz rings 32a and 32b embedded between silicon
rings 31a to 31c. ←

^{The} ~~Said~~ cover 30 can be handled as one disk, and ^{this} improves ^{the}
workability of replacement or the like.

The following describes the case of plasma CVD. Organic
silane based gas, including fluorine, and oxygen gas are
mixed and supplied as ^{the} process gas. ^{The} process gas is decomposed
by ^{the} plasma in the process chamber to form a silicon oxide

^{the}
film on ^asubstrate.

—
—
5 Silicon oxide film adheres not only on the substrate
15, but also on covers 8a to 8d on the surface of the facing
electrode, as well as ^{on the} inner wall surface 1a, etc. As
described above, however, ions ^{are} ~~is~~ ^{the} applied to covers 8a to
8d on the surface of the facing electrode and inner wall
surface 1a at an accelerated rate by application of radio
frequency power. ^{Accordingly, the} Silicon oxide film is removed by the effect
[assistance] ^{these} of ^a ~~this~~ ions and fluorine radicals ^a generated from
10 the fluorine contained in organic silane gas.

As described above, the first Embodiment of the present
invention provides a plasma processing apparatus and ^a
processing method characterized by a wide range of
control ~~the~~ ^d the electron energy state

15

and by the capability of controlling the generation
of radical species, independently of ^{the} processing conditions
and ^{the} uniformity ^a control.

20 It also provides a plasma processing apparatus and
processing method comprising a uniformity control means
ensuring compatibility of plasma uniformity with radical
species control, ion energy control and improved ion
directionality by generation of low pressure high density
25 plasma, said means ^{being} characterized by ^a control capability

independently of such processing conditions as plasma generation power and pressure.

It also provides a plasma processing apparatus and processing method comprising a means to reduce changes of electric characteristics of the semiconductor device due to electric^d influence during plasma processing, said means being capable of ensuring compatibility reduction of changes of electric characteristics of the semiconductor device due to electric^d influence during plasma processing with plasma uniformity control, radical species control, ion energy control and improved ion directionality due to generation of low pressure high density plasma; and, said means^{is} characterized by^a control capability independently of such processing conditions as plasma generation power and pressure.

Figure 10 is a schematic^{diagram} [drawing] representing a plasma processing apparatus as a second Embodiment according to the present invention.

The second Embodiment will be described mainly with regard to the differences from said first Embodiment, with the [same] description^{of overlapping features being} omitted.

The differences^{between} [of] the second Embodiment^{and} [from] the first Embodiment^{is} that a ring block 21 is provided on the outer periphery of facing electrodes 2a and 2b. The ring block 21 is isolated from the insulator 4d, facing electrode 2b, process chamber

1c and cover 8d.

Inductors 12a and 12b and ring block 21 are connected with each other through variable capacitors 22a and 22b, and ring block 21 and process chamber 1c are connected with
5 each other through capacitors 23a and 23b.

The following describes the process treatment^{carried out} in the second Embodiment: ←

→ Emission and control of electromagnetic waves from insulator 4b are the same as those described ^{with} in reference
10 to the first Embodiment. The resonance state of the resonant circuit composed of inductors 12a and variable capacitor 22a and the resonant circuit composed of inductor 12b and variable capacitor 22b is controlled by variable capacitors 22a and 22b, thereby controlling radio frequency
15 displacement current between the facing electrode 2b and ring block 21 and ^{the} distribution in the circumferential direction. ^{Thus} [This], electromagnetic waves from between the ring block 21 and facing electrode 2b are radiated in proportion to this radio frequency displacement current.

20 The second Embodiment provides ^{an} [the] optimum plasma distribution since it enables both independent control of the emission of electromagnetic waves on the inner and outer peripheries of process chamber 1c, and control of distribution in the circumferential direction.

25 In Figures 3 to 5 described above, plasma distribution

is controlled by density distribution 52, 54 and 56 of the plasma generated by electromagnetic waves radiated from the central portion. In the present Embodiment, density distribution 51 of the plasma generated by electromagnetic waves radiated from the outer periphery can also be controlled. In addition, control distribution under axially symmetric conditions and in the circumferential direction can be controlled.

The following describes an example of wired film etching in accordance with the second Embodiment. Substrate 15, where an aluminum film is formed on the silicon oxide film, is installed on the stage electrode 3. After that, chlorine based etching gas is supplied into the process chamber 1c, and the pressure is set to 1 Pa. Then, radio frequency power of 1000W is supplied to the facing electrodes 2a and 2b to generate plasma. Radio frequency power of 100W is applied to the stage electrode 3, and ions applied to the substrate 15 from plasma is accelerated by this radio frequency bias.

On the surface of the substrate 15, a resist mask used for patterning is decomposed by plasma, and a deposition film is formed from the decomposed gas or the like. The deposition film is removed by application of ions, and the exposed aluminum film reacts with chlorine based radical species generated in plasma, thereby ensuring progress of etching.

The deposition film formed on the surface of ^{the} substrate 15 is not formed uniformly. There is a greater volume [of] deposit^{ed} at the central portion. So the volume of ions at the center must be increased to ensure uniform etching.

5 When aluminum etching has^{been} completed and ^{the} underlying silicon oxide film is exposed, etching of ^{the} silicon oxide film proceeds in proportion to the volume of ions. Under the same etching conditions as those of ^{the} aluminum film, a greater amount of silicon oxide film at the central portion
10 will be etched.

Therefore, during etching of ^{the} aluminum film and ^{the} silicon oxide film as an underlying film, ^{the} plasma distribution must be subjected to adequate in-process control according to each condition.

15 In this second Embodiment, variable capacitors 11, 22a and 22b are designed ^{so to be} as ^{or a} variable by means of a drive motor 26, distribution controller 28, ^{or a} similar drive mechanism and control mechanism. This allows plasma distribution to be controlled by the plasma processing apparatus control
20 mechanism, similar ~~to~~ to such processing conditions as pressure and power.

Some processing conditions are set in the controller in the etching system. Processing pressure, radio frequency power to be applied, type and volume of etching
25 gas supplied into the process chamber and the like are

memorized under one^{set of} setting conditions. Etching is carried out by a combination of some of these setting conditions. This combination is also memorized in the controller. The etching system starts processing when the setup conditions and combination (normally called^a recipe) are specified.

^{accordance with}
In the present invention, a control program is designed to allow plasma uniformity as well as pressure and power to be incorporated into this setup condition, to ensure that variable capacitor capacity can be controlled by this specification.

The processing procedures ^{for} [of] etching with plasma uniformity incorporated in this condition will be described with reference to an example of ^{the} aluminum film etching described above. Figure 11 shows ^{the} the relationship between [the] plasma uniformity control and ^{the} elapse of time in this etching procedure.

^{the}
Plasma distribution is controlled by detecting the point where aluminum film etching is changed to silicon oxide film etching, where the detection is made according to the result of monitoring the end point of etching with the monitor 25.

^{the} During etching of ^{the} aluminum film, plasma density is set ^a to convex distribution. Control is ^{carried out} [made] as follows: When the end point of etching is detected by the monitor 25, ^{the} the capacity of variable capacitor 11 is increased by the

drive motor, thereby, ^{obtaining a} [getting] uniform plasma distribution. This state is maintained until the end of etching.

^{The} aluminum film is not formed uniformly; ^{the} film thickness has a distribution. To form fine patterns with high precision, it is necessary to provide [a] high precision control of over-etching time or the like after completion of etching. Etching of ^{the} aluminum film must terminate simultaneously on all surfaces of ^{the} substrate 15.

In the Embodiment according to the present invention, the thickness of the etched film is measured by ^a film thickness measuring means (not illustrated), and ^{the} plasma distribution is controlled for each substrate by counting backward from the result of measuring the film thickness distribution, to ensure that etching is terminated simultaneously on all surfaces of the substrate.

In this control, from the data on the etched film input into the etching controller, ^a calculation is made to obtain the etching rate and distribution which ensure that etching of the etched film ^{will be} (is) terminated simultaneously on all surfaces of the substrate. Then, ^{the} plasma density distribution required for ^{the desired} etching rate is prepared. From the relationship between the capacitor capacity shown in Figure 6 and ^{the} plasma distribution, the capacity of variable capacitors 11, 22a and 22b is calculated, and ^{the} plasma distribution is controlled by the distribution controller

28 and drive motor 26, thereby allowing etching to be carried out.

From the view point of electronic energy control, the second Embodiment has been described mainly ^{with regard to} [regarding the] discharge based plasma processing where the state of ^{the} electron energy is controlled under capacitatively coupled discharge conditions, where ^a magnetic field is not applied, to electronic cyclotron resonant conditions, where ^a magnetic field is applied. Plasma distribution and gas decomposition can also be controlled by discharge where ^a magnetic field is not used.

In the second Embodiment illustrated in Figure 10, electromagnetic wave power applied to the central portion of the process chamber 1c is increased by increasing the displacement current flowing to the resonant circuit formed by variable capacitor 11 and inductors 12a and 12b. Then, electromagnetic wave power is supplied to ^{the} plasma as in the case of ^{an} inductively coupled plasma. However, there is much reflection from ^{the} plasma, and a ^{greater} amount of radio frequency displacement current must be supplied than in the case where ^a magnetic field is used.

Electromagnetic wave power radiated from the outer periphery can be controlled in the same way as that radiated from the central portion ^{, as} described above, by increasing ^{the} displacement current flowing to the resonant circuit formed

by variable capacitors 22a and 22b and inductors 12a and 12b.

5 This allows a double ring plasma on the central portion and outer periphery to be formed in the process chamber 1c by inductive coupling. Uniform plasma can be formed on the large-diameter substrate 15. Furthermore, ^a plasma distribution ranging from ^a convex distribution to ^a concave distribution can be controlled by controlling each of ^{the} displacement current at the central portion and ^{the} radio frequency displacement current on the outer periphery.

10 When this magnetic field is not used, energy is supplied intensively to ^{the} plasma in the vicinity where electromagnetic waves ^{are} ~~is~~ radiated. ^{Thus, the} [So] electronic energy is increased to a high level to facilitate decomposition of ^{the} process gas.

15 Thus, the following conditions can be controlled by the magnetic field formed by variable capacitors 11, 22a and 22b and coil 14 as ^{provided} (shown) in the present Embodiment [2]:
20 (1) a condition where radio frequency displacement current is reduced, and discharge is mostly carried out under the capacitatively coupled condition, (2) a condition where radio frequency displacement current is increased and ^a locally powerful plasma is formed to promote decomposition of ^{the} process gas, and (3) a condition where the travel of electromagnetic waves ^{the} in plasma is facilitated by formation of ^a magnetic field, and slow decomposition of ^{the} process gas

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provided by supply of energy from electromagnetic waves to plasma^{occurs} in the entire process chamber.

The second Embodiment provides a plasma processing apparatus and processing method characterized by a wide
5 [control] range of ^{control of} the state of electron energy as in the case of the first Embodiment, and by the capability of controlling the generation of radical species, independently of processing conditions and uniformity control.

10 In the Embodiment according to the present invention, ^{as} described above, mainly (the) etching and plasma CVD have been described. However, it should not be understood that the present invention is limited only to ^{such processes} (them). It is clear that the present invention is ^{generally} applicable to processes ^{es} using plasma, such as plasma polymerization and sputtering.

15 In the above-mentioned Embodiment according to the present invention, the frequency of the radio frequency power supply for plasma generation has been described for the case where ^{the frequency} (it) is 100 MHz. As described in the first
20 Embodiment, ^a (the) similar effect can be obtained within the range from 200 MHz to 10 MHz.

It is also possible to store in the memory means ^{the} (the) processing procedure for the control of above-mentioned plasma processing distribution, and to control plasma
25 distribution by means of a control means according to the

stored processing procedure, thereby ^{performing} ~~forming~~ plasma processing.

5 The present invention allows the state ^d electron energy to be controlled independently in the plasma processing apparatus. This makes it possible to control generation of radical species, and to ensures compatibility of the characteristics, for example, between etching of high selectivity and high precision, high-speed etching, or film quality and film formation speed, where the compatibility of such characteristics has been difficult to ~~be ensured~~ ^{attain} in the prior art.

15 Furthermore, plasma density distribution can be controlled without changing ^{the} hardware configuration, and minute-pattern high-precision etching and uniform film formation are possible on all surfaces of ^a ~~the~~ large-diameter substrate.

^{The} Plasma distribution can also be controlled during plasma processing, independently of process conditions. Higher precision etching and more uniform film formation can be ensured by controlling plasma distribution in conformity to the progress of plasma processing.

20 ^{accordance with} In ^{an} the present invention, ^{an} electromagnetic wave is radiated by the control of radio frequency displacement current. According to this method, the space for radiating the electromagnetic wave can be made as narrow as about

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0.2 mm, as described in the Embodiment. This method is the same as the inductively RF coupled method in that electromagnetic waves ^{are} ~~(is)~~ radiated, but the space for radiating the electromagnetic waves cannot be reduced to ^{the same as obtained} ~~that~~ extent, according to the inductively RF coupled method. Thus, the present invention has the effect of allowing more stable processing than prior art methods, without being affected by ^a deposition film attached on the wave radiating portion.

10 The present invention further reduces ^{the} occurrence of changes of electric characteristics in semiconductor devices by plasma processing, and provides an effect of improving yields in semiconductor device production.

15 This has ensured a high performance in processing of semiconductor devices and liquid crystal display devices, and provides the effect of permitting higher performance ^{of devices} ~~device~~ production. Namely, the present invention realizes a plasma processing apparatus and processing method which allows independent optimization of each of processing 20 conditions, uniformity control, radical species generation control and prevention of changes in electrical characteristics.

25 The present invention provides the effect of using wide ranging processing conditions, without processing conditions, such as pressure and power, being restricted by

the need for uniformity or prevention of changes in electrical characteristics.

ABSTRACT OF THE DISCLOSURE

The [present invention controls the] state^d electronic energy and generation of radical species^{is controlled} by controlling the electron energy state using electromagnetic waves^a radiated into plasma and magnetic field, and by controlling each state of capacitatively coupled discharge, inductively coupled discharge and electronic cyclotron resonant discharge. [The present invention] Further [controls] the radiated electromagnetic wave power distribution^{is controlled} through displacement current control, and [controls] uniformity in plasma processing^{is controlled} through plasma distribution control. Still further, [it controls] the density distribution of radio frequency current flowing through the substrate^{is controlled}, thereby preventing changes in characteristics of semiconductor devices.